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DESIGN AND CONSTRUCTION OF FABRIC REINFORCED RETAINING WALLS BY NEW YORK STATE

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AD 137 (12/70)

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By

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ABSTRACT

This paper relates the experience of New York State in the design and construction of two fabric-reinforced retaining walls. Crushed stone fill is reinforced by horizontal layers of fabric placed at intervals dependent upon the height of the wall, the strength of the fabric, and the internal friction angle of the fill. Design and construction procedures are detailed, with emphasis on practical construction techniques.

The design and construction is based on methods described by the U. S. Forest Service. The construction technique, although not commonplace, can be quickly mastered without special equipment or labor requirements.

Instrumentation installed during construction to monitor vertical and horizontal movements indicates satisfactory performance 18 months after completion.

The cost of this type of construction at this site compared favorably with alternative designs. Suggestions for cost reductions are offered for future installations, which may include embankment repair, similar to this project, or temporary works, such as construction detours.

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Introduction

New York State Department of Transportation has designed two retaining walls using geotextile fabric as a reinforcing material. The walls, completed in August 1980, repair shallow failures in a side hill embankment of Route 22 in Columbia County. The failures were observed in early 1976, when the easterly shoulder settled several inches in two areas, 125 feet apart. The areas, designated A and B extend for 110 feet and 150 feet, respectively.

A monitoring program was established in the fall of 1976 to measure any vertical or horizontal movements of the pavement, shoulder and embankment slope. A subsurface investigation program was initiated in 1977, consisting of a number of cased drill holes, one of which was converted into a long-term observation hole. The subsurface profile, Figure 1, determined from visual identification of soil samples and analysis of boring logs, shows 5 to 10 feet of loose clayey silt, sandy with gravel overlying similar compact material, with ledgerock encountered at depths varying from 15 to 25 feet.

Movements up to 0.2 feet horizontally and 1.2 feet vertically, detected from 9/76 to 4/78, and distortion of observation hole casing at depths of 4 to 5 feet (see Figure 1), indicated a shallow failure in the loose material rather than a sliding failure along the rock surface. Subsurface water, due to sidehill seepage at Area B and a broken box culvert at Area A, was the primary cause for failure of the 1 vertical on 1-1/2 horizontal embankment slopes. This assumption was supported by the existence of 125 feet of unaffected 1 on 1-1/2 slope between the two failure areas, and the natural flattening of slopes in the wet areas to 1 on 2.5.

The extent of the failures would have required remedial treatment beyond the capability of maintenance forces. Consequently, the Department considered a number of design solutions. The criteria for an acceptable treatment included positive stabilization of the failure areas with low future maintenance, additional shoulder width, and safe traffic control during construction. Traffic restrictions by construction equipment and/or cost considerations eliminated a pile-and-lagging wall and extensive slope treatments. The earth-fabric wall concept was selected as the lowest cost solution meeting the criteria.

Design

The design is based on methods described in a U. S. Forest Service publication (1). The wall is designed as lifts of alternating fabric reinforcement and stone fill, as shown in Figures 2 and 3. The fabric within the theoretical failure zone cannot mobilize tensile strength to resist internal failure, and is therefore discounted when calculating the reinforcing length required. The fabric length embedded behind the theoretical failure plane is the fabric which reinforces the fill. The lift thickness is formed by the fabric which overlaps the face of the wall and retains the fill material.

Site conditions controlled the length and height of each wall necessary to stabilize the failure areas. The cross-section dimensions were determined to satisfy the internal and external stability of the wall. The minimum dimensions for internal stability were calculated with the strength parameters of the fabric and fill material, using appropriate factors of safety. These dimensions were increased to adequately resist lateral pressures acting on the wall, computed according to Rankine theory and the Boussinesq equation.

The reinforcing selected was Bidim C-34, a non-woven, needle-punched, continuous filament polyester fabric with high strength and permeability. The design tensile strength of 75 pounds per inch width of material represents approximately one-third the grab test value (ASTM D-1117-69) reported by the manufacturer, a ratio which agrees with the Oregon State University ring test results for other Bidim weights as reported in (1). Crushed stone was selected as the fill material because of its high permeability and high angle of internal friction. The stone also develops high friction with the fabric, which is necessary to develop fabric tension.

The minimum dimensions calculated to satisfy internal stability did not satisfy the external requirements to resist sliding. This was primarily because of the low friction factor assumed between the fabric and the native material. The factor of safety against sliding was increased by widening the wall to gain mass, and by placing a 2 foot thick foundation of crushed stone beneath the first lift to increase the friction factor. This crushed stone layer also provided positive drainage for the wall and backfill.

The final cross-section dimensions, shown in Figure 3, were obtained by adjusting the calculated values to use the full manufactured width of fabric rolls, 17.4 feet. The wall was designed in two tiers, each with a different maximum lift thickness. The two tier design was selected for practicality in construction, since the theoretical lift thickness may vary continuously with depth and pressure below the top of the wall. The overlap dimension was allowed to vary with the lift thickness to keep the wall width constant.

Construction

The site was prepared for wall construction using normal clearing

procedures. However, the grubbing operation took care not to disrupt the root systems of two large white pine trees adjacent to the limits of failure Area A.

The excavation was progressed to the limits shown in Figure 3 while maintaining one-way traffic on the adjacent lane. The excavation was confined to one lane by using a 1 vertical on 1 horizontal backslope as the steepest allowable unbraced slope. The excavation was benched at elevations determined from analysis of boring logs and confirmed by field inspection, to remove weakened material and establish the wall foundation on undisturbed compact soil. The transition between benches and the end slopes were 1 vertical on 2 horizontal.

An additional 2 feet of soil was removed below the base elevation and replaced with a crushed stone foundation layer, as mentioned earlier. The excavation was continued at this elevation to the natural slope to provide a continuous drainage path from within and behind the wall. Wherever the distance from the toe of the wall to the existing slope exceeded 10 feet, French drains were installed, 20 feet on center, to provide positive drainage. This reduced the volume of excavation and stone backfill required. In Area B, because of sidehill seepage, a separation layer of filter fabric was placed on the backslope of the excavation to prevent contamination of the stone backfill, Figure 8. Area A did not require this treatment, because there would be no seepage after the culvert was repaired under this contract.

This project incorporated recommendations from (1) to improve the temporary form. With the exception of placing the crushed stone foundation and drainage layer, the sequence for wall construction was also performed as

recommended by the Forest Service (1). The construction sequence consisted of the following steps, which were repeated in order, until the wall reached full height.

- The temporary form system was placed to line and grade. (Figure 4)
- The fabric was positioned, with the excess draped outside the form. (Figure 5)
- Crushed stone was placed to approximately one-half lift thickness, reaching full thickness at the face. (Figure 6)
- The excess fabric was folded back to overlap the fill, and the lift was completed to full thickness, burying the overlap. (Figure 7)
- The fill was compacted, and the temporary forms were removed. (Figure 8)

The fabric was placed horizontally, with the long dimension parallel to the centerline. Crushed stone was placed using one of several methods depending on the work area available. First, the contractor tried end-dumping the stone and placing it by hand. This method, which proved to be too laborious and time-consuming, was quickly abandoned in favor of dumping stone from a front end loader, and backblading to the approximate thickness. Hand labor was necessary only to form the berm and overlap at the face. When the construction area increased sufficiently, the front end loader supplied stone and a small dozer was used for grading.

Each lift was compacted using a "walk-behind" ("hand-guided"), double drum vibratory compactor with successive passes made parallel to the centerline, progressing from the backslope to the temporary form. When the work area increased, a small ride-on vibratory roller was used. Thorough compaction

was desired at the wall face, to minimize post-construction settlements and horizontal movements in this area. However, the specified minimum of four passes was reduced to two passes, when observations showed the compaction effort was penetrating several underlying lifts. After the form was removed, the vertical face gradually became curved as overlying lifts were compacted. Even when thoroughly compacted, the fabric at the face did not appear highly stressed, and could actually be pinched by ordinary finger pressure.

The fabric was chosen mainly for its strength and permeability, although some resistance to ultra-violet deterioration was also desired. The maximum allowable exposure time for the fabric was specified as two weeks. However, for permanent protection, low-maintenance, and vandal protection, the wall face was covered with a mesh-reinforced pneumatically projected concrete. The reinforcing mesh, specified to be manufactured from No. 12 wires spaced 2 inches in each direction, was supported using No. 3 rebars inserted between layers to a depth of 3 feet. The bars were placed between layers during construction to form a grid measuring 3 feet by 3 feet. The mesh was included to minimize possible settlement cracks in the rigid concrete surface of the flexible wall. (Figure 9)

Instrumentation

The walls were instrumented to investigate vertical and horizontal movements. Each wall was instrumented at the section of maximum height, which generally corresponded to the area of maximum past distress. Slope indicators and settlement devices were installed to monitor the behavior of the foundation soil. Slip tubes (Figure 10) were placed within the wall to detect lateral movements of the stone fill perpendicular to the wall face. The

fabric was not instrumented. Minimal construction delays (typically only one-half hour) were required to install a set of slip tubes or settlement devices which were pre-fabricated and installed by State forces. Installing the slope indicator casing, also done by State forces required several days of drilling. However, the contractor was able to schedule work without any conflicts.

Two settlement devices were installed under each wall, 6 feet and 10 feet from the toe. The change in fluid level at the readout measures the cumulative foundation settlement. These devices measure the change to 0.01 feet, which is sufficiently accurate to detect significant movements.

The settlements measured during construction were less than one-quarter inch. At Wall B, the settlement measured one year after construction was 1.32 inches at both devices. At Wall A, settlements measured eight months after construction were 0.5 inches and 0.25 inches at the devices 6 feet and 10 feet from the toe of the wall, respectively. (These were the last measurements before the Wall A devices were vandalized.) These settlements have caused no noticeable effect on the roadway structure or the rigid concrete face.

The slope indicator casing was installed just outside the toe of the wall. The magnitude and direction of foundation movement with respect to depth can be measured as a change from the original slope of the casing. Foundation movements can thus be isolated, and any subsequent lateral movements detected by the slip tubes will indicate movement within the wall. Measurements made one year after construction indicate no significant foundation movement at either wall, which verifies the earlier assumption of a shallow failure.

A slip tube (Figure 10) is free to slide on an anchor rod which extends 3 feet beyond the tube. Internal horizontal movements of the fill, are indicated by the change in distance between the end of the slip tube and a scribe mark on the inner rod. The scribe mark is referenced to an external control line. Thus, the relative movement and the absolute movement of the tube can be determined.

The tubes were installed in sets of four at various elevations to investigate the pattern of lateral movement. The tubes were buried 3, 6, 9, and 12 feet into the wall, with each anchor rod extended 3 additional feet beyond its respective tube. With anchors equal in length to the longer of the adjacent tubes, the wall is divided into several observation zones. Movements were compared within sets of tubes, and with corresponding length tubes at different elevations. Many tubes showed no movement while others have not exceeded 0.25 inches, as late as one year after construction. Possibly, any short-term movements occurred during construction, before the control points were set, or only small movements have occurred. Generally, the shorter tubes have shown the most movement, although continued monitoring may reveal a more definite pattern.

Lessons From Field Experience

The contract plans originally specified crushed stone with a 2-1/2 inch maximum size. A substitution was allowed at the contractor's expense to reduce the maximum size to 1-1/2 inches. The smaller stone also provides a sufficent friction angle for this design, but is easier to place by hand. This change, combined with improved handling methods developed during this project, increased the contractor's daily production. For example, exclusive

of face treatment, the first wall, which has a surface area of 1630 square feet required two weeks for construction. The second wall, with a surface area of 2100 square feet, was also constructed in two weeks.

The fabric layers were placed horizontally without splices. Longitudinal splices were eliminated by designing the total fabric dimensions to equal the 17.4 foot roll width commercially available. Transverse splices were permitted, if necessary, by specifying a minimum overlap of 2 feet, or a 6 inch minimum overlap, field-sewn double-stitched using nylon or polypropylene thread. On this project, the contractor elected to place all lifts as a single piece of fabric. Consequently, we have no comments on the success or use of splices, beyond the suggestion above regarding transverse splicing, and a concurrence with others (1), that splices parallel to the wall face should be expressly prohibited.

Moisture was observed at the wall face before the fabric was covered with concrete. This was possibly due to surface water collecting in areas where irregular pockets formed in the fabric, or perhaps, where the fabric became clogged with rock dust. Future installations should consider placing the fabric horizontally in the longitudinal dimension, but sloping the fabric toward the rear of the wall for positve drainage, especially if the face treatment will be impervious.

Compaction vibrated some stone fill out of the open ends of lower lifts. This loss of fill was prevented by folding the fabric to form a "bed corner." Figure 11. This figure also shows how the upper lifts were stepped to follow the grade of the road. At the south end of Wall A, each lift was folded to bend the wall back to meet the flatter existing slope, Figure 12. The north

end of each wall intercepted the natural slope, and was buried with light stone fill, after the face treatment was applied.

The rebar grid set for the reinforcing mesh required the addition of a top and bottom row. These bars were installed after construction with minimal effect on the fabric. Future installations should specify a top and bottom row of rebars. The 3 foot square grid should be modified, perhaps by staggering alternate rows of rebars. Construction joints in the concrete face seem desirable to reduce cracking. Vertical construction joints, 50 feet on center, were included in the second wall.

The volume of concrete used on the facing exceeded the estimate by 40 percent, even with the thickness reduced from 3 to 2-1/2 inches. This increase occurred because the ribbed surface of the wall and the wall batter formed a shelf between each lift.

Cost

The cost, including items for excavation, fabric, stone fill and concrete facing, was $42 per square foot of wall face. This exceeds the 1978 estimate by $10 per square foot. This increase relects the haul distance for the stone (35 mi) as well as the increased volume of concrete facing. The percentage break-down by items was 10 percent for excavation, 30 percent for fabric, 40 percent for stone and 20 percent for concrete.

Conclusions

Fabric reinforced retaining walls can be built quickly and easily without extraordinary equipment or labor requirements. The wall can be shaped to the site by such methods as benching, bending and stepping the lifts. The primary considerations in construction are compaction of the stone fill and drainage

accommodations. The temporary forms necessary to confine the face area during compaction can be fabricated from common materials.

The instruments used were adequate to detect post-construction movements. However, the slip-tubes could not be adequately monitored during construction. Future installations should attempt to account for this condition, or perhaps restrict observations to the external face of the wall. The arrangement with the contractor for installing instrumentation was satisfactory, since the instruments were prefabricated to minimize delay.

The cost of this project compared favorably to other alternatives at this site. Cost reductions are possible by using a cheaper fill material. However, positive drainage must be provided, by using a very permeable fill, or by constructing a permeable zone behind and beneath the wall. Also, a cheaper face treatment will reduce costs significantly.

Acknowledgements

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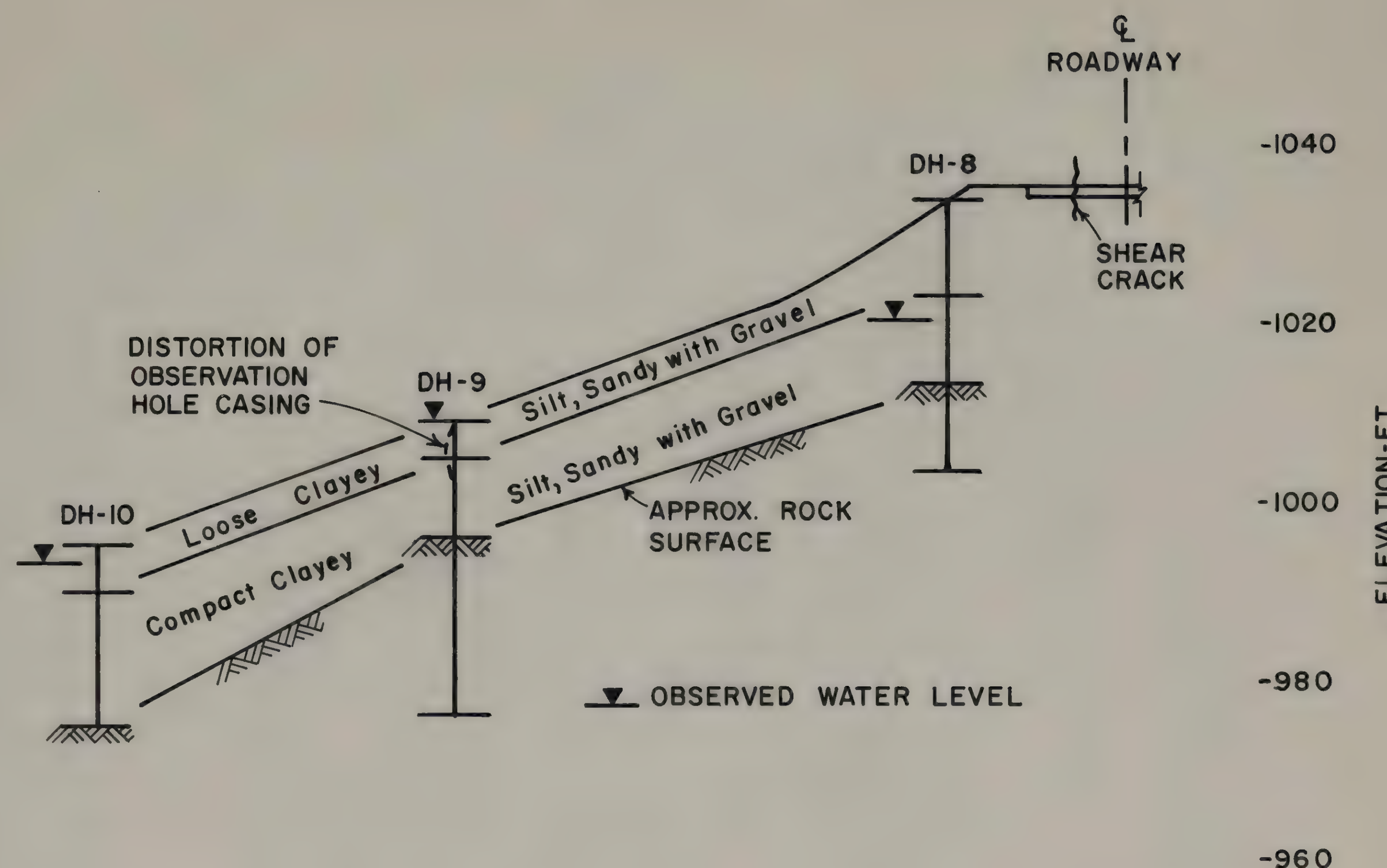
The efforts of M. Duval, Engineer-in-Charge for the State, and S. Cornell, supervisor for Schultz Construction, Inc., were uniquely responsible for the quality of the structure, and the innovative solutions to field problems detailed herein.

References

1. J. Steward, R. Williamson, J. Mohney. "Guidelines for Use of Fabrics in Construction and Maintenance of Low Volume Roads." Chapter 5, Earth Reinforcement. Prepared by Forest Service (Pacific Northwest Region), U. S. Department of Agriculture. Reprinted by Federal Highway Administration, U. S. Department of Transportation, Report No. FHWA-TS-78-205.

FIGURE TITLES



TYPICAL SUBSURFACE PROFILE AT FAILURE LOCATION

FIGURE 1

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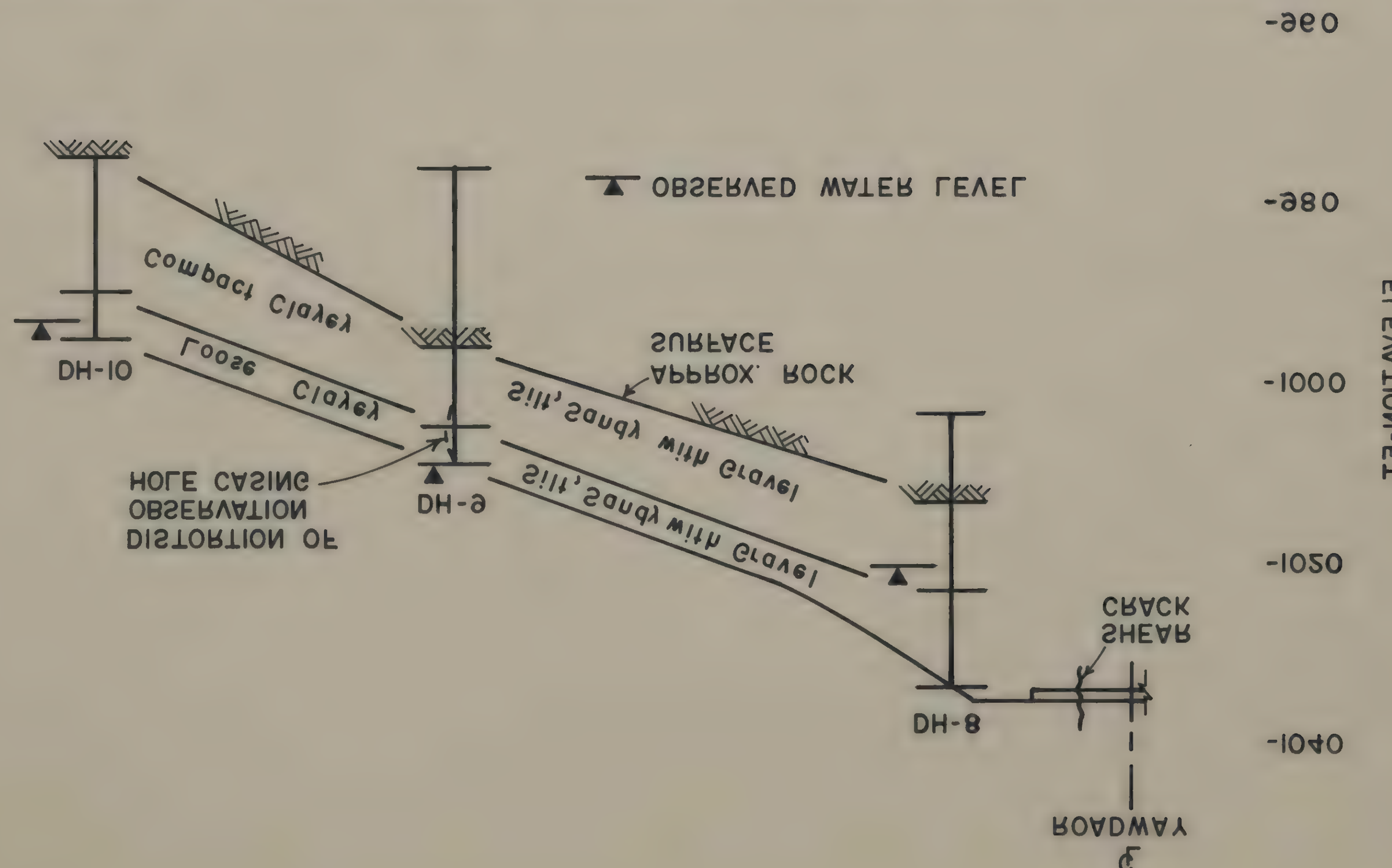
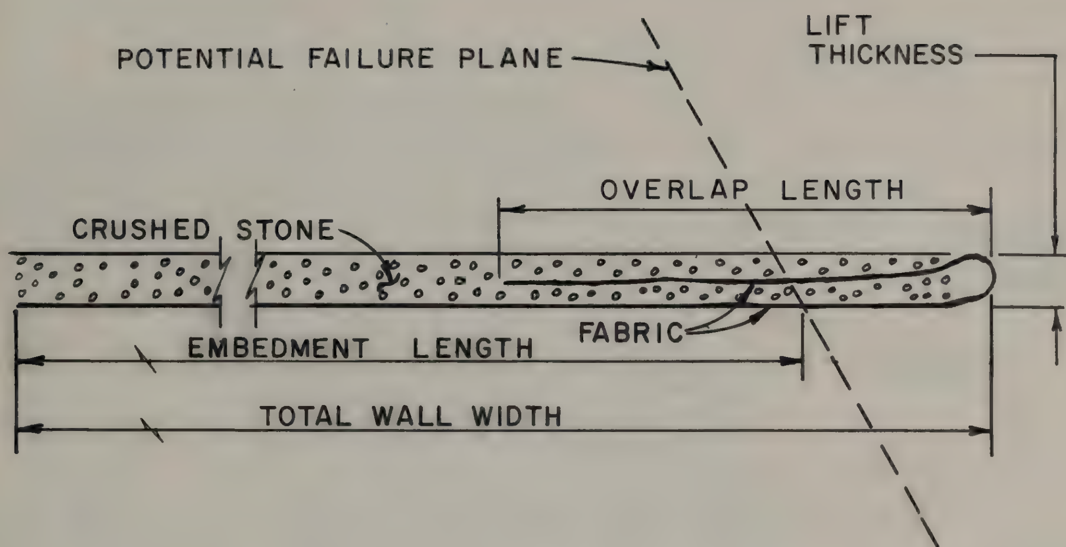


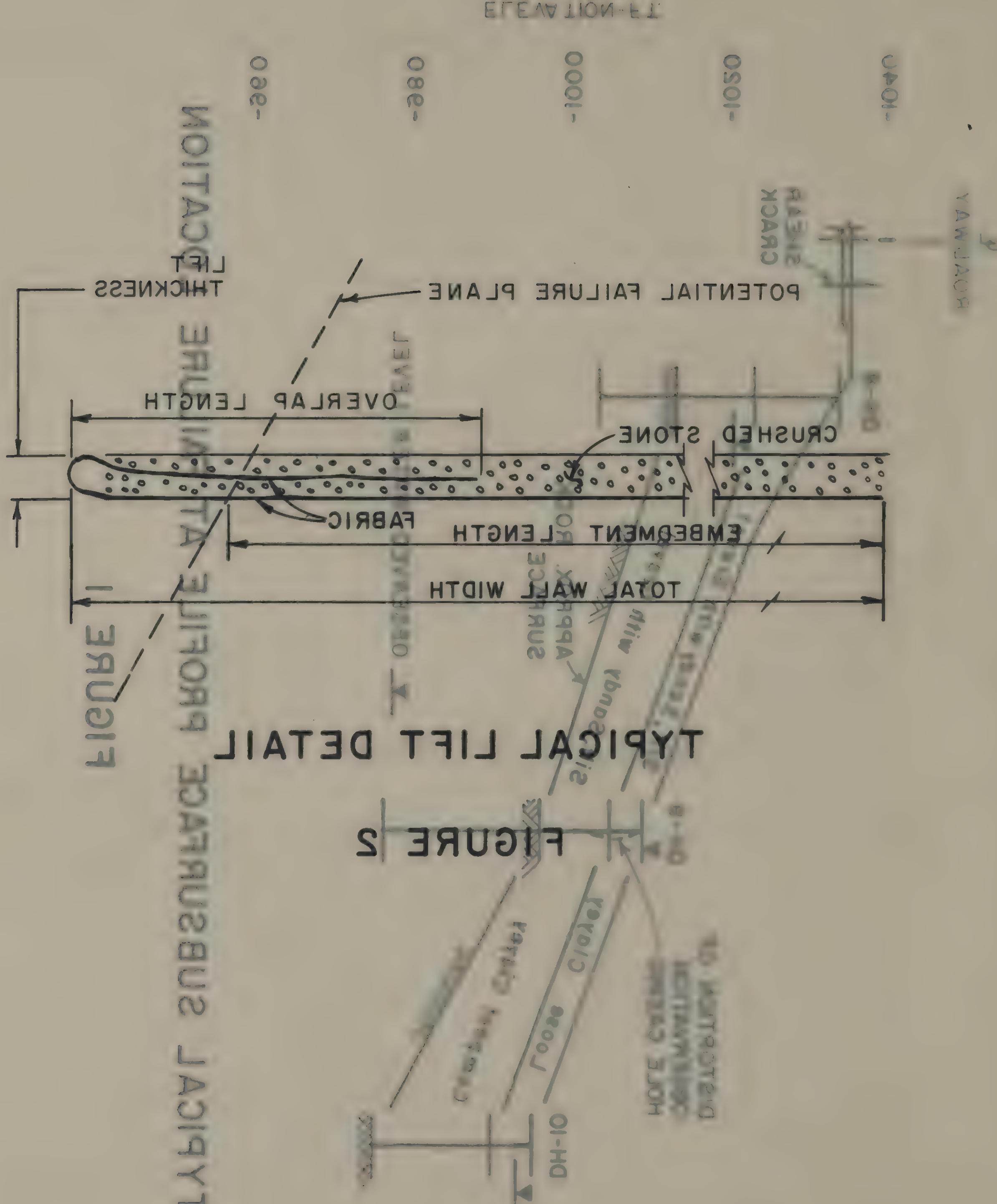
TYPICAL SUBSURFACE PROFILE AT FAILURE LOCATION

FIGURE 1



TYPICAL LIFT DETAIL

FIGURE 2

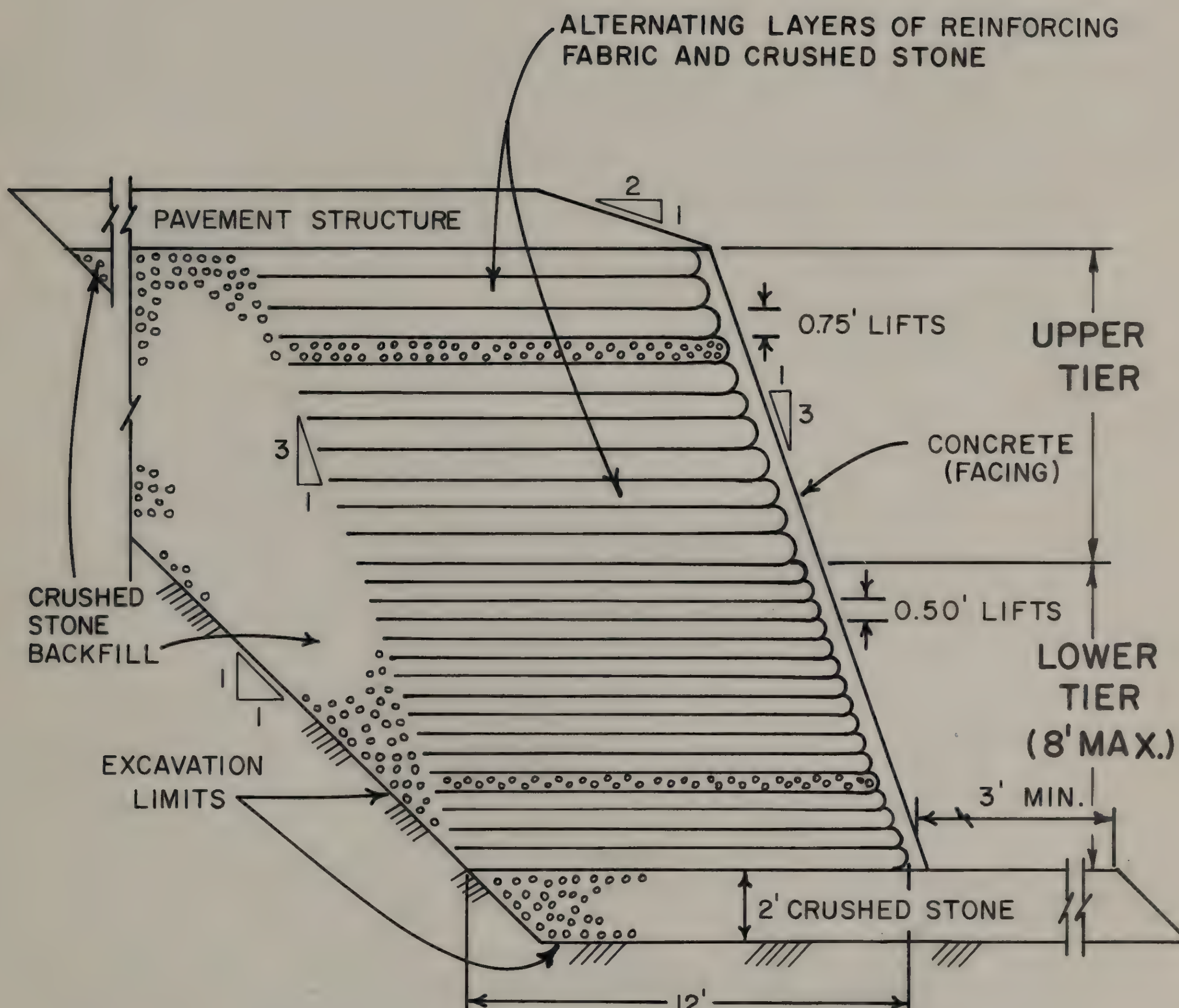


TYPICAL LIFT DETAIL

FIGURE 2

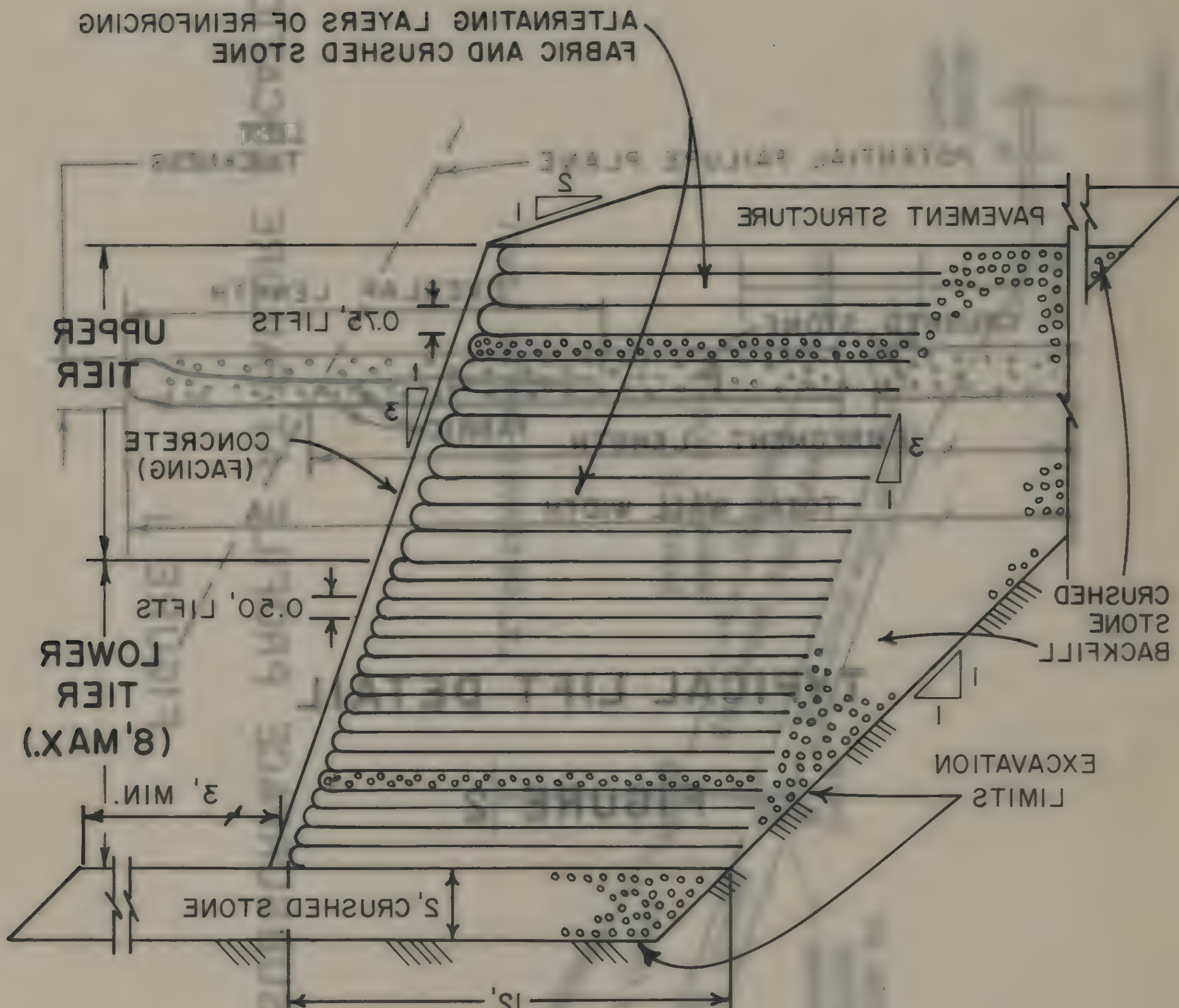
TYPICAL SUBSURFACE PROFILE AT FAILURE LOCATION

FIGURE 1



TYPICAL WALL SECTION

FIGURE 3



TYPICAL WALL SECTION

FIGURE 3

PLACING TEMPORARY FORMS

FIGURE 4

POSITIONING THE FABRIC

FIGURE 5

FORMING THE BERM FOR THE OVERLAP

FIGURE 6

BURYING THE OVERLAP LENGTH

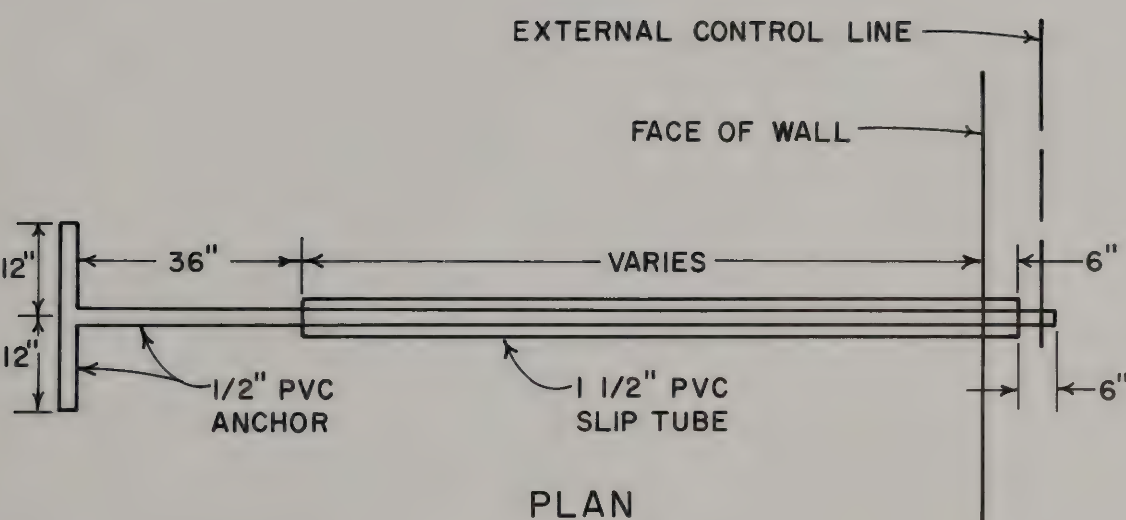
FIGURE 7

COMPACTING A COMPLETED LIFT

FIGURE 8

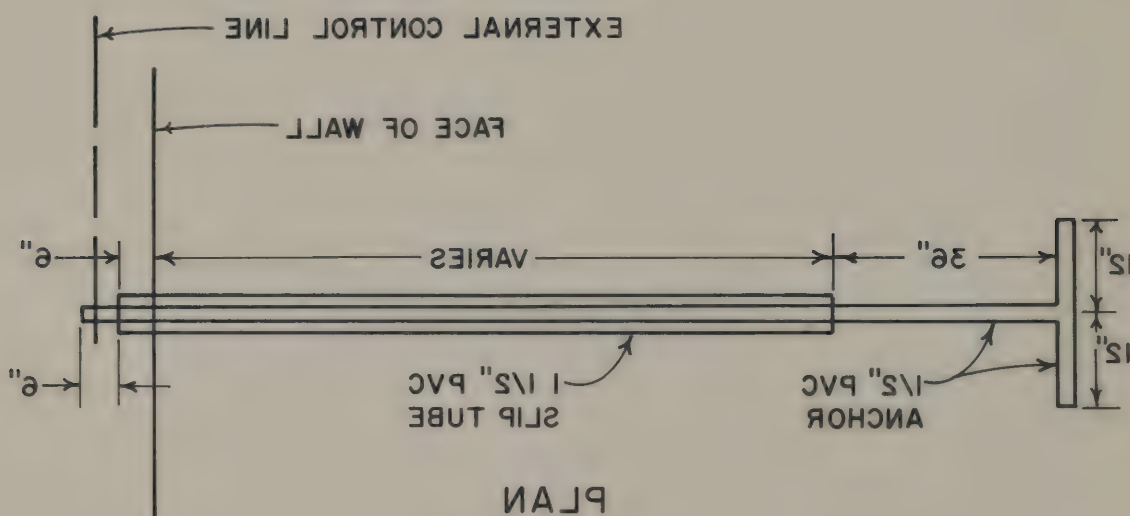
CONCRETE FINISH ON FACE OF WALL

FIGURE 9



TYPICAL SLIP TUBE

FIGURE 10



TYPICAL SLIP TUBE

FIGURE 10

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STEPPING THE LIFTS TO FOLLOW GRADE

FIGURE II

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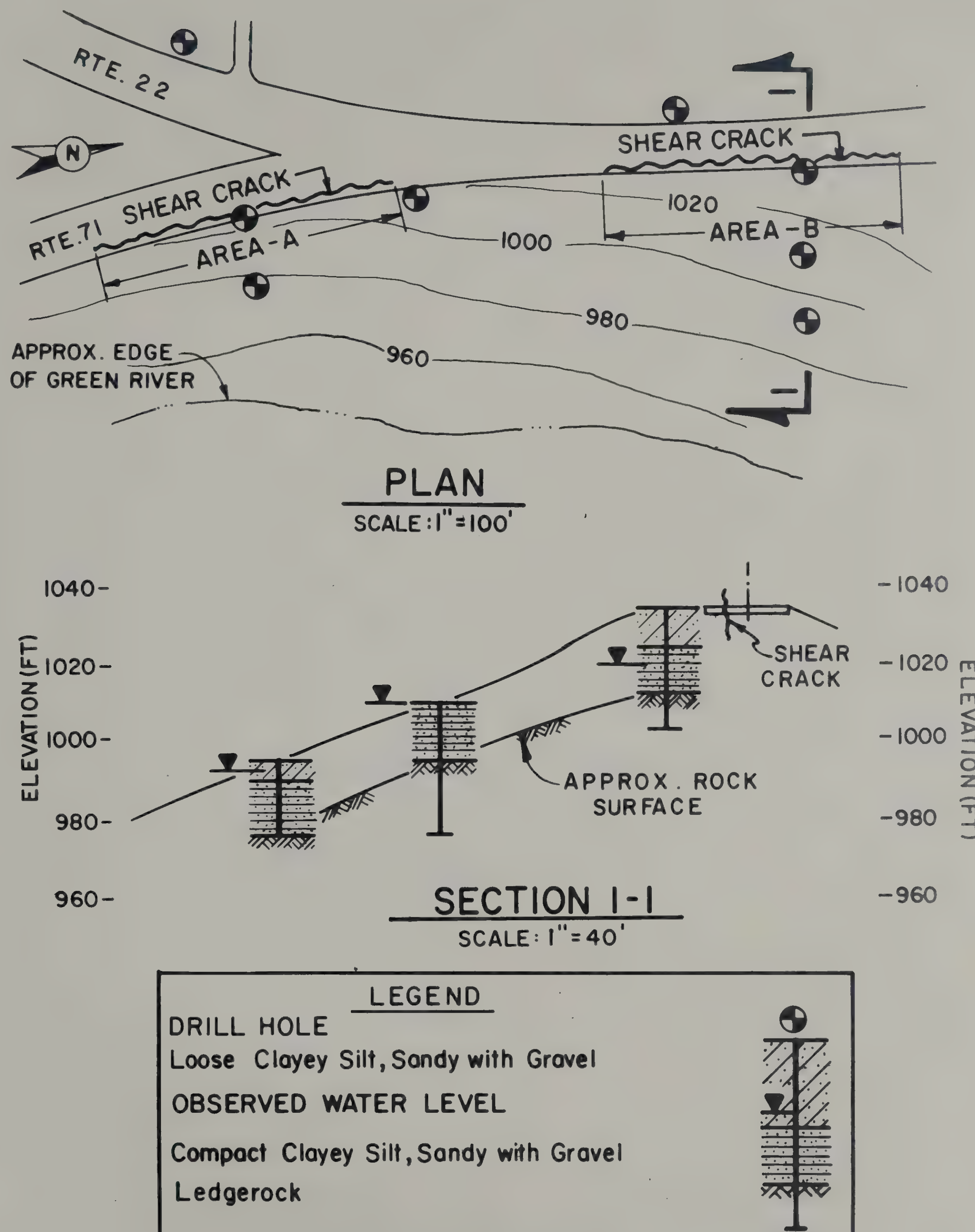
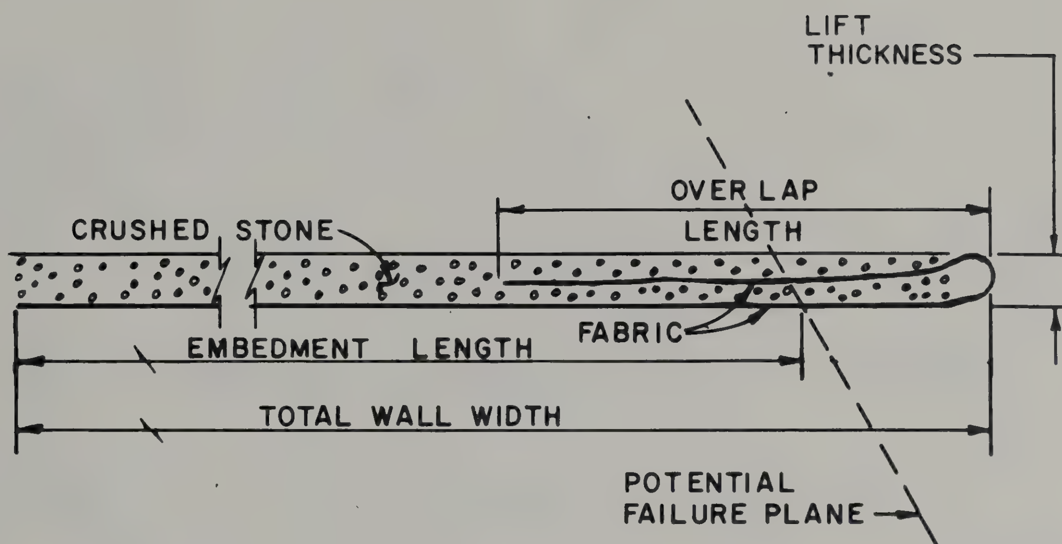
BENDING THE WALL TO MEET EXISTING SLOPE

FIGURE 12



FAILURE LOCATION
AND TYPICAL SUBSURFACE PROFILE

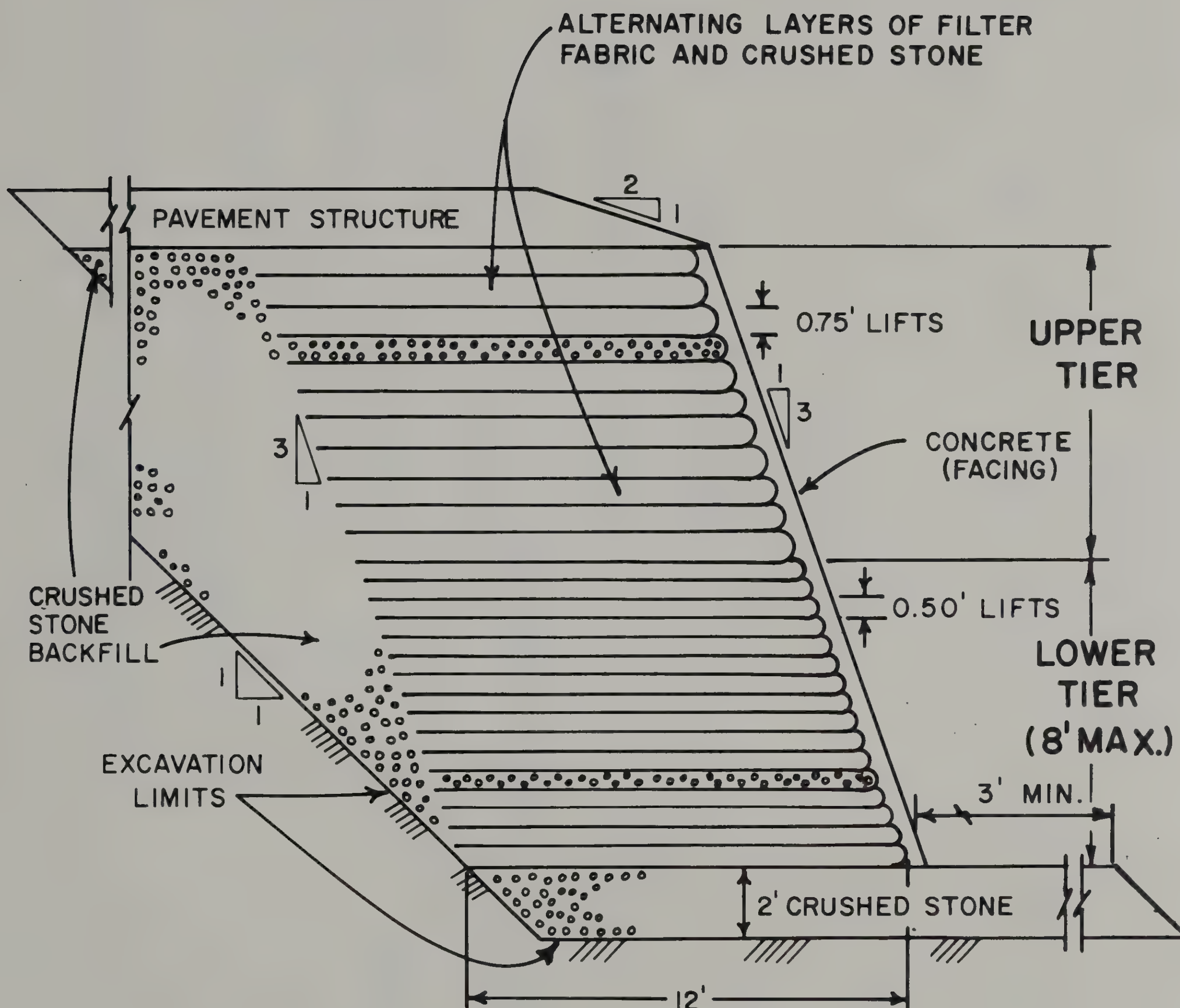
FIGURE 1



TYPICAL LIFT DETAIL

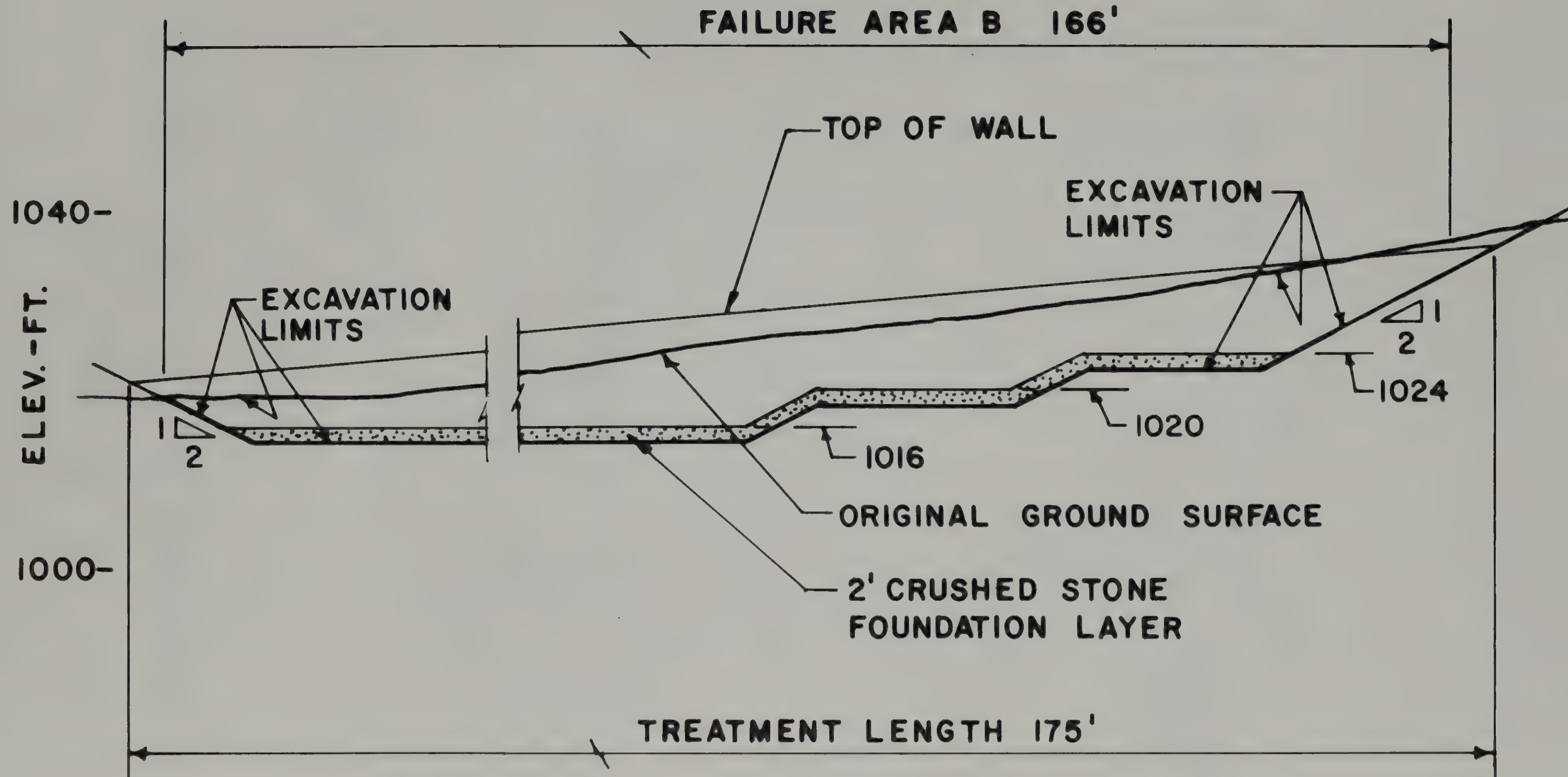
NOT TO SCALE

FIGURE 2



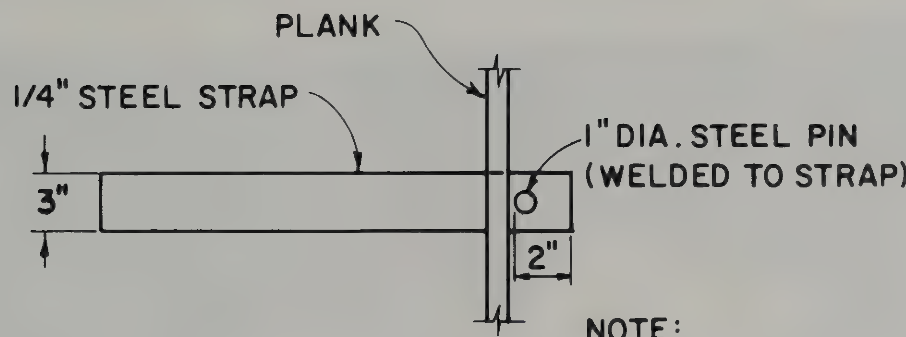
TYPICAL WALL SECTION

FIGURE 3

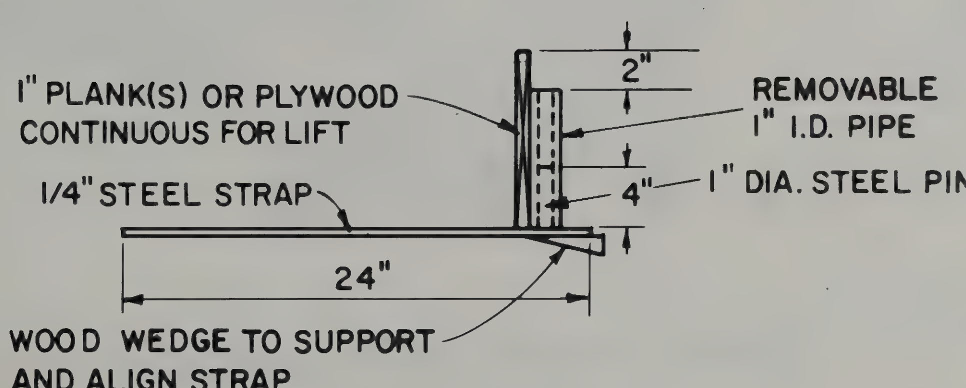


EXCAVATION LIMITS FOR AREA B

FIGURE 4



PLAN



ELEVATION

TEMPORARY FORM SYSTEM

FIGURE 5

ALIGNING TEMPORARY FORMS

FIGURE 6A

PLACING TEMPORARY FORMS AT GRADE

FIGURE 6B

POSITIONING THE FABRIC

FIGURE 7A

SAVING FABRIC FOR THE OVERLAP

FIGURE 7B

FORMING THE BERM FOR THE OVERLAP

FIGURE 8

BURYING THE OVERLAP LENGTH

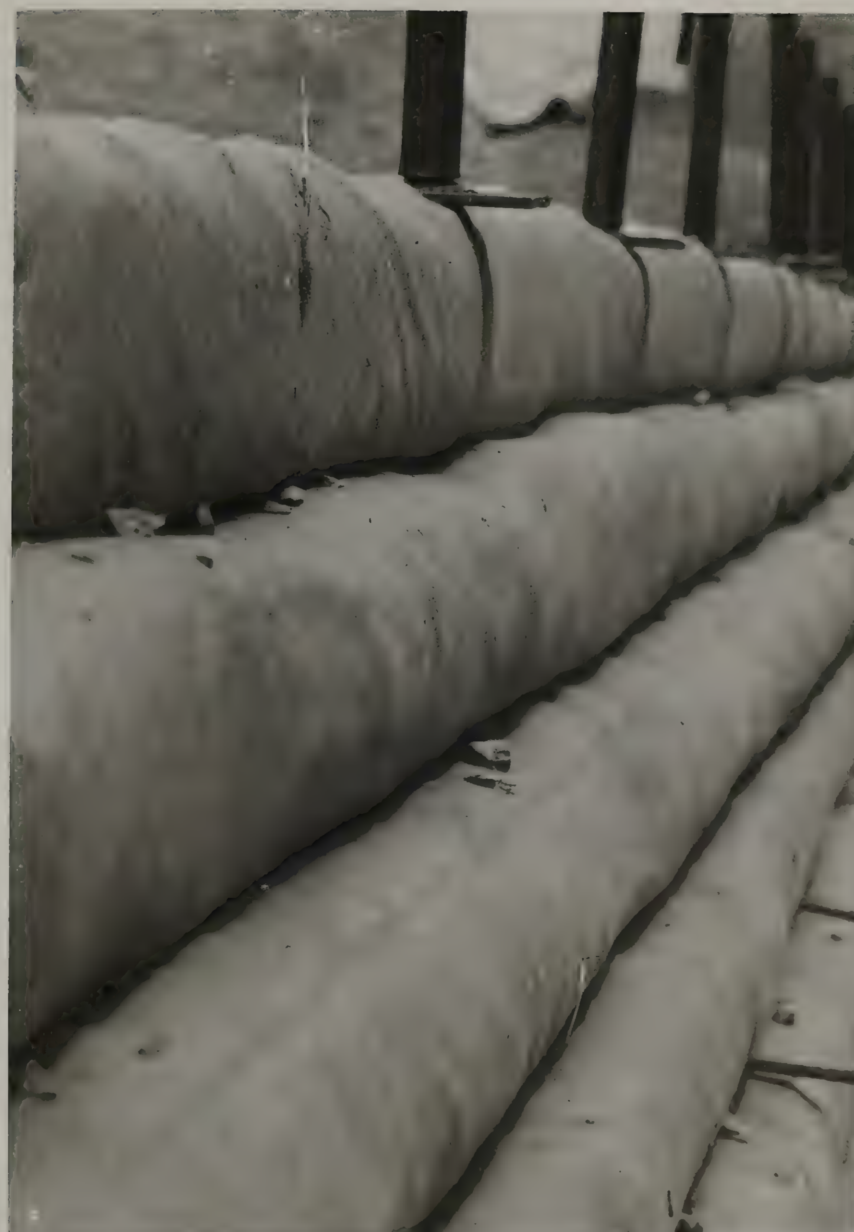
FIGURE 9

COMPLETING LIFT FILL

FIGURE 10

COMPACTING A COMPLETED LIFT

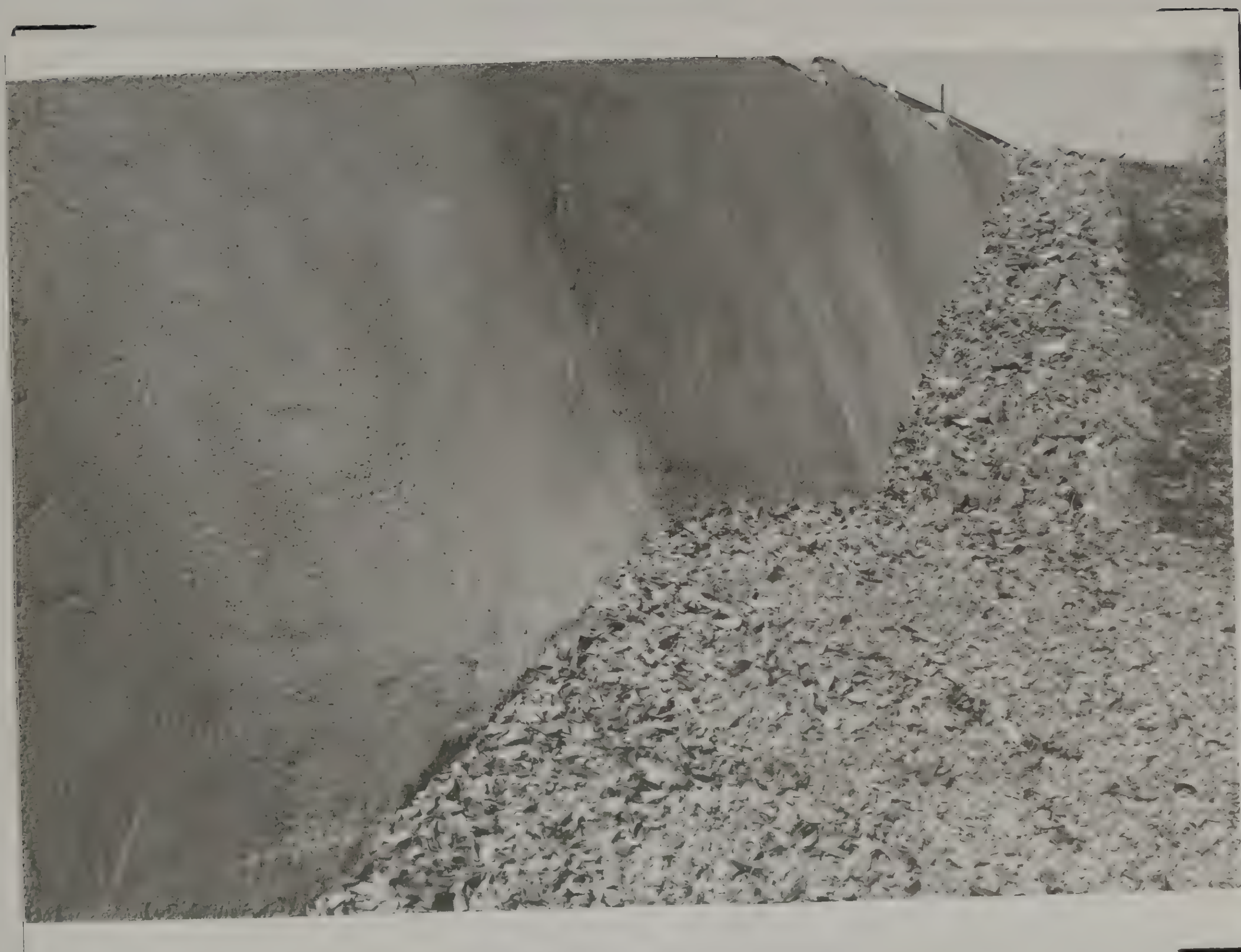
FIGURE II



WALL FACE SHOWING EFFECTS OF
COMPACTION ON UNDERLYING LIFTS
FIGURE 12

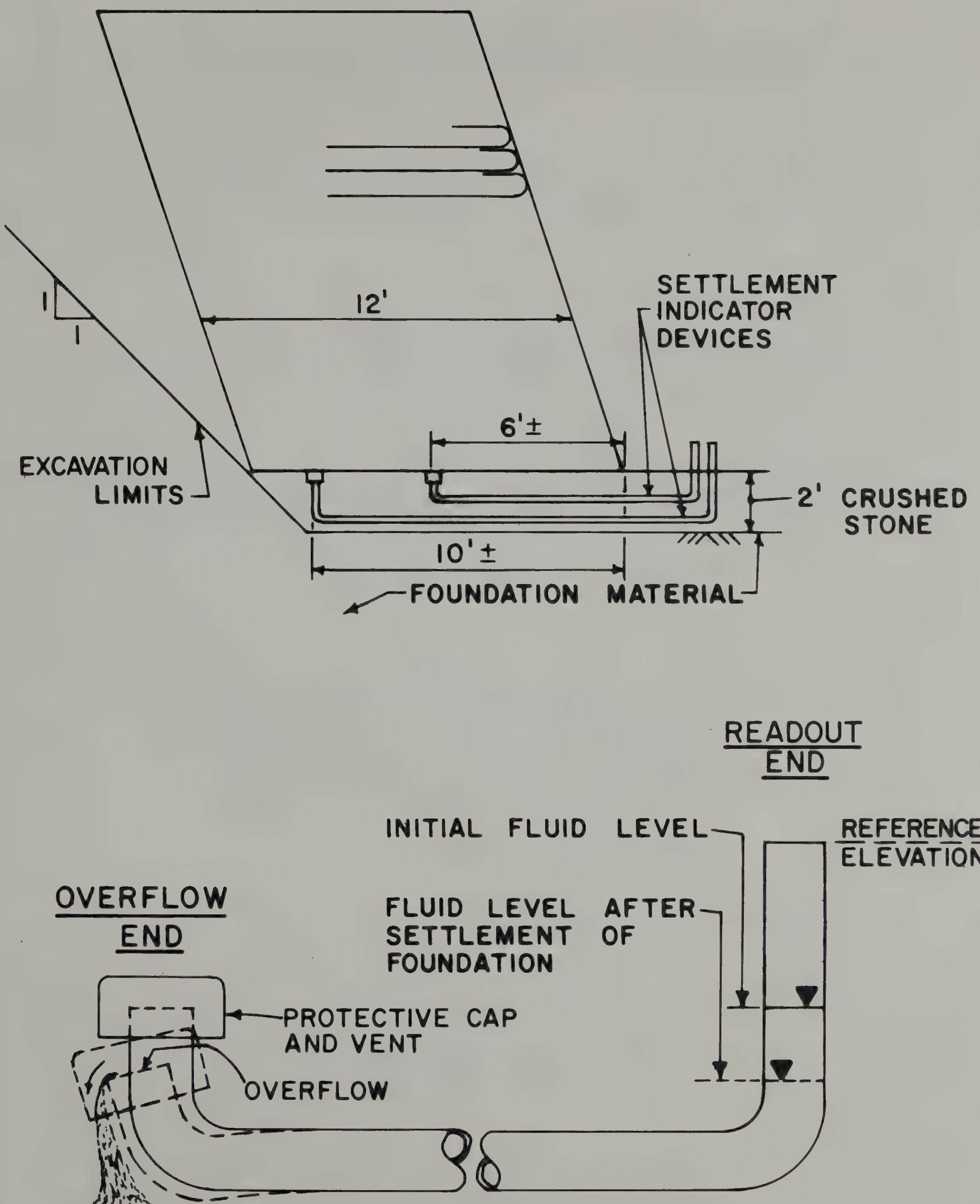
WALL FACE WITH REINFORCING MESH IN PLACE

FIGURE 13



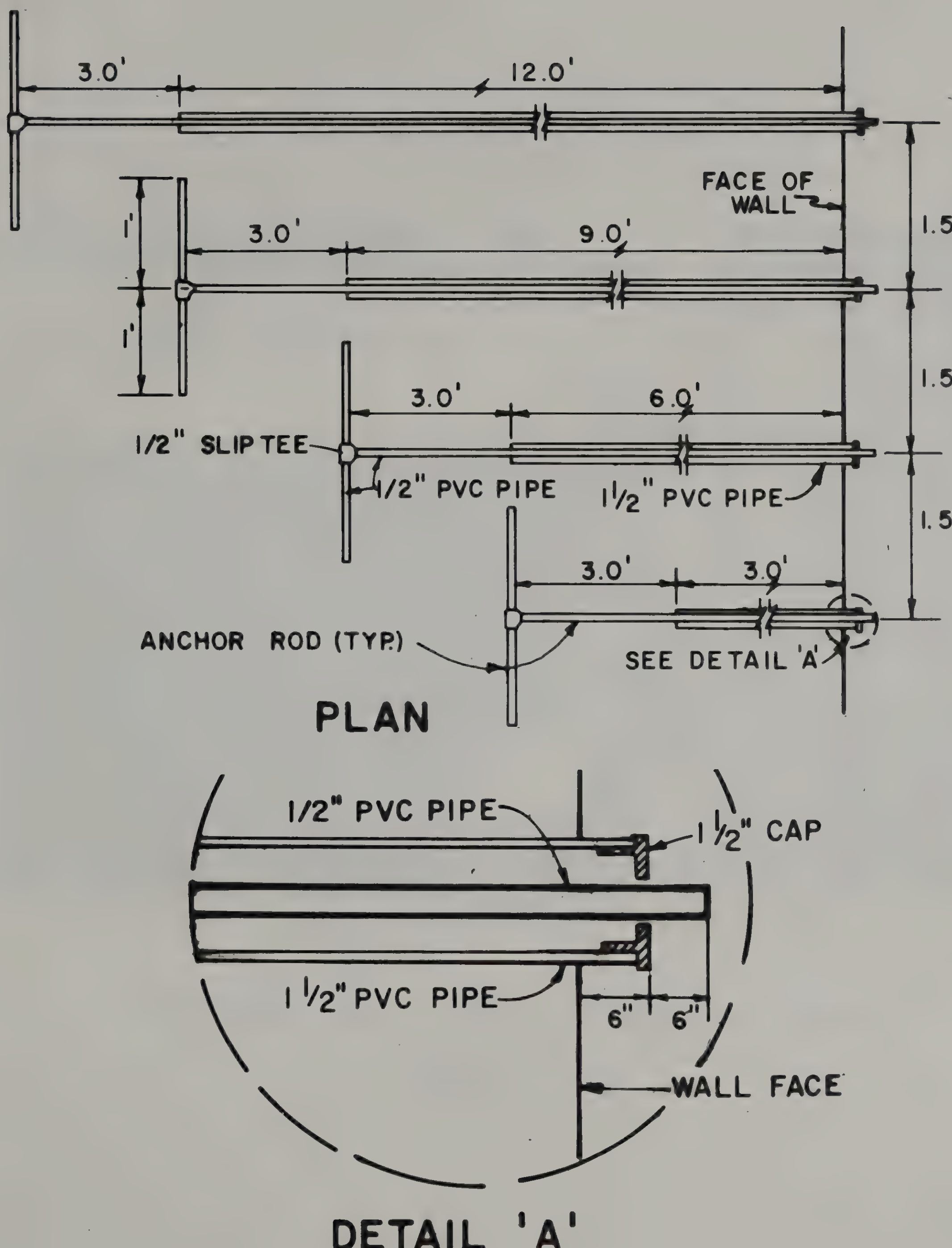
CONCRETE FINISH ON FACE OF WALL

FIGURE 14



SETTLEMENT INDICATOR INSTALLATION

FIGURE 15



TYPICAL SLIP TUBE INSTALLATION

FIGURE 16

STEPPING THE LIFTS TO FOLLOW GRADE

FIGURE 17

END OF LIFT, UNCONFINED

FIGURE 18

"BED CORNER" TO CONFINE LIFT

FIGURE 19

BENDING THE WALL TO MEET EXISTING SLOPE

FIGURE 20

TRANSPORTATION RESEARCH RECORD 872

Centrifuge-Soil Testing, Soil Mechanics, and Soil Properties

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